Original Research

Solids Waste Gas Recovery Under Different Water Conditions

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Abstract

This papers deals with the determination of the influence of water and landfill leachate dosage on the quality and quantity of municipal waste biogas. Wastes used in the experiment were collected from a municipal landfill located in Łęgajny near Olsztyn. Gas production (total gas volume, production rates and methane concentration) was monitored for 311 days. The quality and quantity of biogas were determined as for waste deposition without irrigation and with irrigation with the addition of water and leachate (the amount was typical for the average atmospheric precipitation and double amount of atmospheric precipitation). Moreover, the researches were carried out for totally flooded wastes.

It was shown that there is an influence of water conditions on the biogas production. The lowest biogas production was observed for waste deposition without water and leachate irrigation (dry wastes) and for totally flooded wastes. Obtained biogas characterized the lowest amount of methane. The highest effectiveness of biogas production and its best composition was achieved for wastes irrigated by leachate in the amount corresponded to atmospheric precipitation. Biogas contained about 50% of methane.

Research showed that there is the possibility of biochemical processes controlling in waste heap (e.g. in energy piles); however, there is then the necessity of optimization of the dosage and kind of recirculated medium.

Keywords: biogas, methane production, municipal solid waste, leachate

Introduction

Biogas that is produced in the waste heap in the landfills is potentially environmentally hazards. The negative effects of biogas can be dangerous for landfill exploitation and natural environments. If biogas cannot escape it can blow up the waste heap and cause its sliding. Migrating biogas can accumulate in empty spaces such as foundations, cellars, inspection chambers or wells, etc., and can cause explosion hazard (5-15 % of methane and oxygen mixture is explosive). Biogas migration to soil layer limits oxygen penetration to the roots and causes plant mortification. Its higher concentrations in the atmosphere contribute to "greenhouse effect". Methane influence is almost 30-fold higher that for carbon dioxide. The counteraction generally consists in waste isolation from the surrounding area through the bottom, sides and landfill-cap sealing. Moreover, it can be collected in gas pipeline and next used or disposed of in a controlled way.

Biogas harvesting is numbered among sustainable waste management [1, 2]. This undertaking is profitable and appropriate owing to environmental protection.

Landfill biogas is the result of the biochemical transformations of the organic fractions in the landfills. On the basis of theoretical considerations it is known that leachate recirculation has a positive effect on biochemical changes in landfill, including biogas production.

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The "Energy pile" is a relatively new and interesting disposal method for wastes containing large amount of organic substances [2]. Energy piles consist of some sealing, draining sections with leachate and biogas collectors where there are optimal conditions to biochemical changes controlling by means of leachate recirculation.

Landfill biogas is a potentially renewable energy source. A review by Richards et al. [3] identified 242 sites in 20 nations where landfill gas was being tapped and used as a fuel with total energy contribution exceeding 2.037 mtcepa (million tones of coal equivalent per annum). The three biggest users of landfill gas are the U.S.A., the U.K. and Germany. Biodegradation of refuse may be a long-term process for real refuse landfill. Nevertheless, bioreaction occurs in a most intensive pattern in a period of 0-6 months after placement of refuse of landfill [4].

The quality and quantity of biogas depend not only on a lot of exterior factors such as atmospheric pressure, temperature and precipitation, but also on interior ones – waste composition and its density, water conditions in landfill.

In a typical landfill, the continuous deposition of solid waste results in high densities and the organic content of the solid waste undergoes microbial decomposition. Initially, while the contained oxygen lasts, the decomposition is mainly aerobic. Then once anaerobic (anoxic) conditions have been achieved various reactions such as acidogenesis, along with formation of organic acids and carbon dioxide, takes place. Finally, methanogenesis also takes place leading to methane formation [5]. Different time estimates have been put forward for the phases of decomposition of organic matter in a landfill [6]. However, in general, in temperate climate landfill gas recovery becomes well established after 1-2 years of solid waste deposition and can be continued for at least the next 15-25 years or longer. Over the past 10 years experimental testing and field pilot studies have been conducted to develop and improve landfill techniques and designs, the goal being to control the negative effects of landfill sites on the environment [7]. Hence, laboratory scale lysimeters are often used to simulate refuse degradation behaviors in landfills [8].

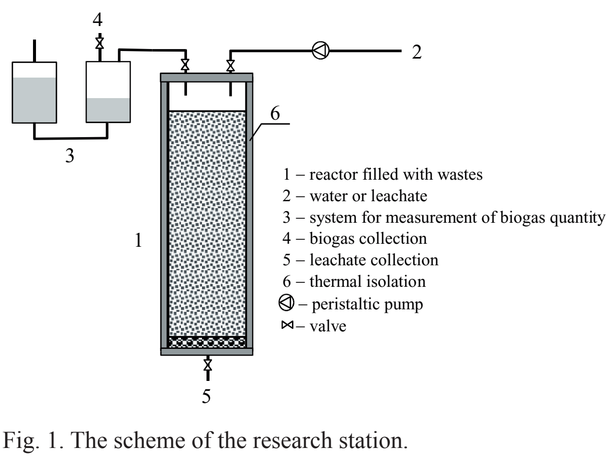


Fig. 1. The scheme of the research station.

Table. 1 Sieve analysis of wastes.

Fraction [%]			
> 120 mm	120 – 40 mm	40 – 8 mm	8 – 0 mm
3.8	28.6	52.5	15.1

Table 2. Average refuse composition used in original forms (wet basis).

Composition	Weight percentages
Cooking wastes	9.7
Paper	15
Plastics	3.9
Cloth	3.5
Glass	6.7
Metals	1.7
Organic wastes	39.7
Rest mineral fraction	3.3
Fine fraction	16.5
Total	100
Water (moisture)	38.1

The aim of the presented study is the determination of how water and leachate management can influence biochemical transformations and biogas production in landfills. The researches should help at control of energy pile exploitation.

Experimental Procedures

The research station consists of 6 lysimeters at a working volume of 44 dm^3 filled with municipal wastes. Each lysimeter was fitted out with stub pipes. It lets on gas collection and the measurement of the volume of the biogas. Moreover, it makes possible water or leachate supplying or samples of leachate collection. Lysimeters were thermally isolated. The scheme of the research station is presented in Fig. 1.

Lysimeters were filled with a waste mixture collected from a municipal landfill located in Łęgajny near Olsztyn. Before filling the lysimeters, analysis of fraction composition (Tab.1) and morphological waste analysis were done (Tab. 2).

At the bottom of each lysimeter there were 10 cm gravel layers on which wastes were put. The wastes were put partially, in the amount of 5 dm^3 (about 10 cm thickness). After filling the lysimeter the wastes were concentrated identically. Top layer in all lysimeters was 10 cm gravel layer.

The research lasted 311 days. During the experimental period the wastes in the lysimeters were supplied by water

Table 3. Physical and chemical properties of the leachate used in the investigations.

	Mean	Range
Reaction (pH)	8.87	8.19 – 9.08
Conductivity (mS/cm)	8.2	7.4 – 9.9
COD (mg/dm3)	3915	2665 – 4352
Total P (mg/dm3)	20.8	16.6 – 31.8
Total N (mg/dm3)	442	385 – 490
Sulfate (mg/dm3)	274	238 – 327
Dry residue (mg/dm3)	8618	7344 – 10628
Residual after combustion (%)	79	73 – 85
Loss at combustion (%)	21	15 – 27

or leachate from landfill located in Łęgajny near Olsztyn. There were the following variants:
lysimeter 1 – without water or leachate (control)
lysimeter 2 – water – 2.15 mm/d
lysimeter 3 – water – 4.30 mm/d
lysimeter 4 – flooded with water
lysimeter 5 – leachate – 2.15 mm/d
lysimeter 6 – leachate – 4.30 mm/d

Characteristics of the leachate used in the experiment are shown in Table 3.

The research was carried out at room temperature about 20°C. Biogas amount was measured every day. Biogas quantity analyses were done 4 times during the experimental period. Biogas was assayed for the following gases: methane, carbon dioxide, nitrogen, oxygen and hydrogen. Analyses of biogas quantity were performed at the Institute of Mining and Gas Oil in Warsaw.

Results and Discussion

Anaerobic biodegradation of municipal solid wastes is a complex and dynamic biochemical process. The main factors influencing biogas production is the content of organic substances in wastes, its susceptibility to biodegradation and moisture.

Water content is the most important factor that has an impact on the rate of waste degradation. It has many functions at the fermentation process in a landfill: it dissolves metabolites, has an influence on enzyme and bacterial nutrient transport and on the accessibility of bacteria to substrate surfaces. Water is an appropriate environment to mass, nutrients, inhibitors, enzymes and microbes replacement in a landfill.

The results of the tests showing the influence of the quantity of supplied solution (water or leachate) on the amount of biogas are presented in Fig. 2.

The amount of collected biogas per unit weight of organic fraction of MSW is shown in Table 4.

Table 4. The amount of biogas produced from 1 g of dry mass of organic fraction of municipal wastes during 311 days of the experiment.

	Biogas amount [cm^3/g d.m. of organic fraction]
Lysimeter 1	3.313
Lysimeter 2	2.818
Lysimeter 3	3.710
Lysimeter 4	0.825
Lysimeter 5	4.151
Lysimeter 6	4.070

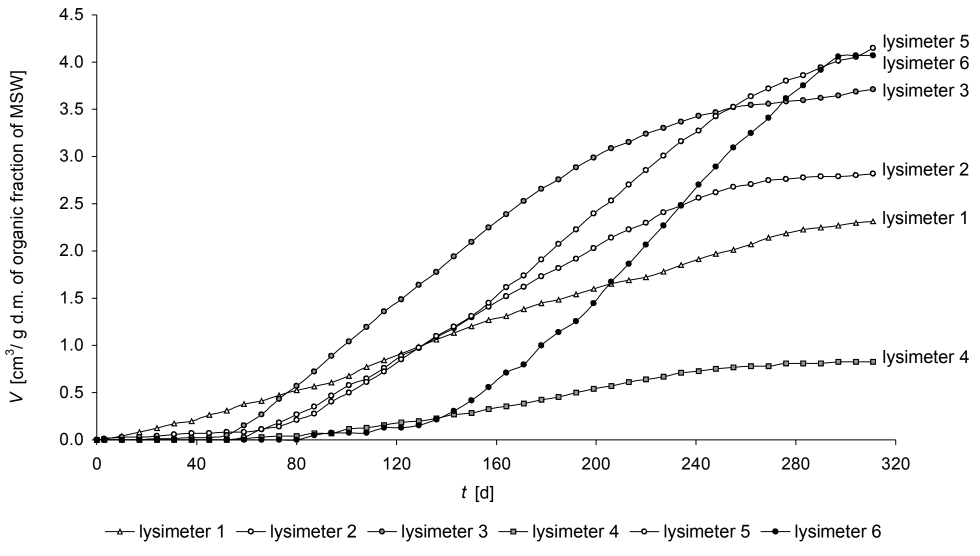
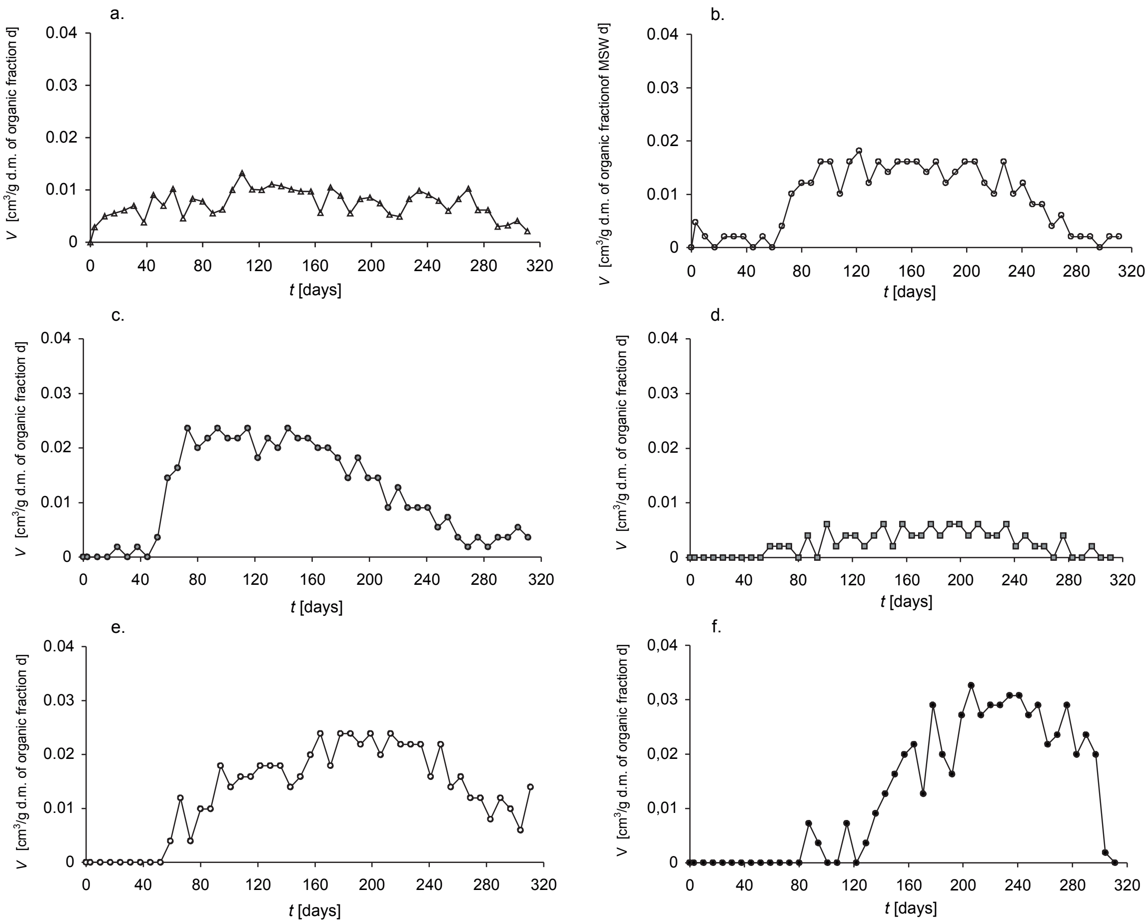


Fig. 2. Cumulative landfill gas production in lysimeters during the 311 days of the experiment.



a. lysimeter 1 b. lysimeter 2 c. lysimeter 3 d. lysimeter 4 e. lysimeter 5 f. lysimeter 6

Fig. 3. Daily amount of produced biogas during 311 days of the experiment.

The presented data show that the amount of biogas depends on the quantity and type of added medium well, on the water conditions in a landfill. In lysimeter 1, where water conditions were not changed, the amount of biogas was on the level of 3.313 cm^3/g d.m. of organic fraction. Using water in lysimeters 2 and 3 caused an increase in biogas production in the amount of 2.818 cm^3/g d.m. of organic fraction and 3.710 cm^3/g d.m. of organic fraction, respectively. Leachate proportioning to wastes in lysimeters 5 and 6 caused higher increase in biogas production and its amounts were adequately 4.151 cm^3/g d.m. of organic fraction and 4.070 cm^3/g d.m. of organic fraction. In contrast to lysimeter 1 (control) the amount of produced biogas was about 1.8-fold higher. The lowest effectiveness of biogas production was observed in lysimeter 4 – 0.825 cm^3/g d.m. of organic fraction. The wastes in this lysimeter were totally flooded by water.

Comparing the quantities of biogas produced in lysimeters 2 and 3 supplied by water with the quantities in lysimeters 5 and 6 supplied by the same amounts of leachate, it can be concluded that leachate caused the increase in biogas production, irrespective of leachate dosage.

Fig. 3 presents the daily amount of produced biogas in lysimeters during the experimental period.

In control lysimeter (lysimeter 1) from the beginning of the experiment biogas production increased systematically. The highest effectiveness of biogas production in this lysimeter (0.01 cm^3/g d.m. of organic fraction per day) was observed between 100 and 180 days of the experimental period. Using water in lysimeters 2 and 3 inhibited biochemical changes and biogas production during 40-60 days of the experiment. After this time, biogas production increased to 0.016-0.024 cm^3/g d.m. of organic fraction per day (it was 2-fold higher production in contrary to control lysimeter). Using landfill leachate (in lysimeter 5 and 6) caused the inhibition of biochemical changes during the initial 60-80 days of the experiment. The highest effectiveness of biogas production in these lysimeters was obtained between 180 and 280 day of the experiment, about 80-100 days later than in control lysimeter. After this period biogas production increased to the amount of 0.024-0.031 cm^3/g d.m. of organic fraction per day and it was a 3-fold higher production compared with control lysimeter. The highest effectiveness of biogas production on the level of 0.033 cm^3/g d.m. of organic fraction per

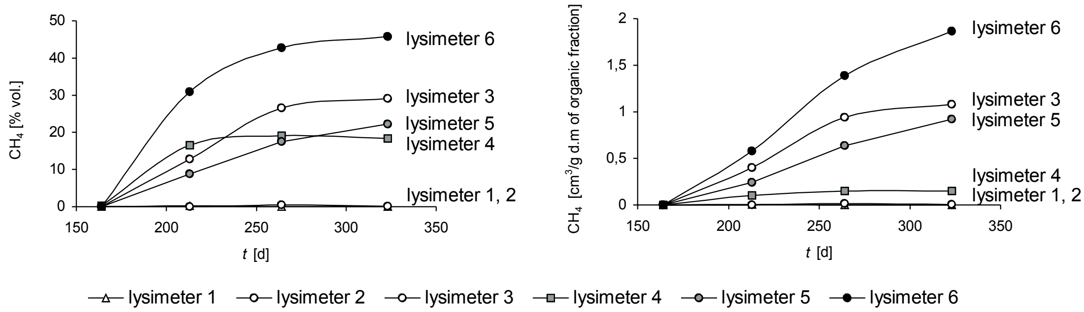


Fig. 4. Methane production in lysimeters during 311 days of the experiment.

day was observed in lysimeter 6 supplied by leachate in the amount of 4.30 mm/d.

Comparing biogas production in lysimeter 3 supplied by water in the amount of 4.30 mm/d to the lysimeter 6 supplied by the same amount of leachate, it can be noticed that leachate inhibited biogas production by about 60 days. The highest effectiveness of biogas production was observed between 70 and 140 days of the experiment. The lowest daily effectiveness - about 0.006 cm^3/g d.m. of organic fraction per day was achieved in lysimeter 4, where wastes were totally flooded by water.

Water is an appropriate environment to mass nutrients, inhibitors, enzymes and microbe replacements in a landfill. Minimal water contents in wastes, at which fermentation started, is about 25%; however, optimal moisture for efficient landfill stabilization ranged from 60 to 70%. It is very important to maintain similar wastes moisture in the whole mass. The initial moisture of wastes used in the experiment in all lysimeters was on the level of 38.1%, a lower value than the optimal one. Too high waste moisture inhibits fermentation, which is confirmed by obtained results. The lowest effectiveness of biogas production was observed in lysimeter 4 filled with totally flooded wastes. This can be the result of the physical properties of water and leachate. High thermal capacity and conductivity of water can cause a decrease in waste temperature, which slows down fermentation and biogas production. Moreover, water can supply and transport the oxygen what inhibit anaerobic bacteria activity. These factors could have an impact on the time after that biogas appeared in the particular lysimeters. Biogas was produced first in lysimeter 1, which did not interfere with water conditions. Increasing water and especially leachate dosages, so upsetting present conditions caused the time needed for methanogenic microorganism generation to be longer.

Organic solid waste biodegradation is the result of aerobic and anaerobic bacteria activity. Among all important bacterial groups needed for complete anaerobic fermentation, it is indicated by a shortage of methanogenic microorganisms in new wastes. Proper growth of these microorganisms in the initial period of landfill existence is decisive for its exploitation as a fermentative reactor. During waste collection in the landfill, aerobic bacteria and fungi use oxygen by the time until its concentration decreases to the level that does not make possible these organisms existence. Accessibility of water can stimulate methane and carbon dioxide production. CO_2 releasing by aerobic microorganisms is conductive to sustainable conditions in which anaerobic microorganisms can grow favourably.

A long transitional period before active methanogenesis is especially true for dry landfills with limited water inflow. Gas production from anaerobic degradation depends mainly on the composition of the biodegradable fraction of waste and its moisture content [9]. The promoted biological activity affects the flow paths of the water. As degradation proceeds, it weakens the structure of the waste, channels within the waste will collapse [10], and thus the water finds new pathways. Flow path may also be reopened when gas production declines, as gas partially blocks the pores in the landfill. Other factors forcing the water to find new flow path are chemical precipitation and biological clogging in the pores of the waste body [11].

The analysis of landfill biogas production does not explain clearly biochemical transformations in waste heap. Despite the fact that biogas appeard in the particular lysimeters between 0 and 80 days of the experiment, methane was present after 210 days, but not in all lysimetrs. The best biogas parameters (the highest percentage of methane content in total biogas volume) was observed in lysimeytr 6 supplied by leachate in double amount af the annual atmospheric precipitation - 4.30 mm/d [Fig. 4]. Methane content was almost 50% of the biogas volume.

Lower methane content was achieved in lysimeter of 3 supplied by water in the amount of 4.30 mm/d. Research revealed that high waste moisture has a positive influence on methanogenesis. Even in totally flooded lysimetr 4, where biogas production was lowest, methane content was relatively high – about 20%. Methane did not appear in biogas in lysimeters 1 and 2 during the experimental period. It just goes to show that in collected wastes there were unfavourable conditions for fermentation.

From the presented experiment it was found that in order to analyze the biochemical transformation in wastes in the landfill, the analysis of both parameters – the efficiency of biogas production and its composition are essential.

Table 5. The volume of methane in lysimeters produced from 1 g of dry mass of organic fraction after 311 days.

	Methane volume [cm³/g d.m. of organic fraction]
Lysimeter 1	0.000
Lysimeter 2	0.005
Lysimeter 3	1.079
Lysimeter 4	0.152
Lysimeter 5	0.921
Lysimeter 6	1.863

Analysis of just one of these parametrs can result in false conclusions, which is confirmed by the results obtained in lysimeters 1, 2 and 4.

The effectiveness of methane production in lysimeter 6 is comparable with the results obtained by Stroot [12] − 53.6% (fermentation of organic fraction of municipal solid waste and sewage sludge), Del Borgi [13] − 50% (fermentation of organic fraction of municipal solid waste and sewage sludge) and Ledakowicz, Kaczorek [14] − 50-60% (wastes mixture at model composition, typical for Łódź, enriched in compost). The effectiveness of biogas production obtained in research is often used as an additional index describing an experiment and the efficiency of the process. Sosnowski and Ledakowicz [15] showed the combination of the literature date concerning the parameters of methane fermentation and obtained effectiveness of biogas production. From the presented date it can be concluded that the effectiveness of biogas production per amount of dry mass of organic fraction, obtained in different experiments and methane content in total biogas volume are similar and do not depend on the method of process performing. In presented study the correlation between the amount of produced biogas, its composition and the method of process performing was observed. The volume of methane in lysimeters produced from 1 g of dry mass of organic fraction is shown in Table 5.

The highest methane volume from 1 g of dry mass of organic fraction of MSW, 0.1863 cm^3, was achieved in a lysimeter supplied by leachate in the amount of 4.30 mm/d. From the comparison of biogas production in lysimeters supplied by water with biogas production in lysimeters supplied by leachate it is showed that the amount of methane obtained from 1 g of dry mass of organic fraction of MSW was higher when wastes were irrigated by leachate.

Chan et al. [16] found that leachate recirculation can shorten the transitional period for active methane production and boost the methanogenesis of a landfill cell containing mixed municipal solid waste, sewage sludge and marine dredgings. The rate of recirculation is important for the enhancement of degradation [11]. According to Townsend et al. [17], laboratory studies, landfill lysimeters and controlled landfill cells have all demonstrated that increasing the moisture content and practicing leachate recirculation have a positive effect on waste stabilization. The degree of enhancement can be significant. In 1982 Klink and Ham [see 18] noted for an increase in methane production rate of 25-50% in experiments with recirculation compared to those without. Similar results were obtained in the presented experiment. At leachate dosage on the level of 2.15 mm/d biogas amount was 50% higher than for the same dosage of water. However, vestigial methane content in biogas in lysimeter supplied by water was observed in contrast to a lysimeter supplied by leachate where methane content was about 22% of total volume. At double water and leachate dosage, 4.30 mm/d the difference in the amount of biogas, was 10%; however, methane content was 29% of the total volume in case of water addition and 47% in case of leachate addition.

A larger volume of recirculated leachate will, according to the results of Chugh et al. [18], promote the establishment of methanogenic conditions, as well as increasing the methane production rate. However, it is unclear whether the increased methane production rate was due to the increased rate only or it if is an effect of the increased inoculation of methanogenic bacteria as well. During an initial period, the recirculating water was inoculated with methanogenic bacteria by circulation of the leachate over a reactor with stabilized waste (exhausted of its methane producing potential). The amount of water may hence not be the only reason for increased degradability due to recirculation [11].

From the presented experiment results that double increase in water dosage caused 1.5-fold increase in biogas amount. However, at double increase in leachate dosage the amount of biogas was higher by 8%.

Warith [19] noted that the addition of supplemental materials to the leachate during recirculation was found to have a positive effect on the rate of biological degradation of municipal solid waste.

This indicates the necessity of control of water content in wastes, which is confirmed by the presented research. Results in this paper were obtained at similar wastes density in all lysimeters. We can summarize at this point that the effects that can be caused by water or leachate addition to wastes depend not only on moisture degree and types of waste but also on waste density. As for wastes at high moisture, its high initial density exclude water taking by waste. The amount of water absorbed by wastes is inversely proportional to solid waste density. The increase in waste density can stimulate intensive biogas production. It is explained as dry waste "wringing out" at higher density and there is the increase in water amount accessible for microorganisms. In order to promote fermentation, waste moisture should be controlled. This allows proper initiation of methanogenesis and the production of biogas at parameters allowing its use in practice.

Obtained results indicate the necessity for special selection of recirculated water or leachate dosage. Too high amount of added recirculate can have a negative influence on the process and biogas production can be lower than in case of lack of recirculation. This is confirmed by the results in lysimeter with totally flooded wastes. In case of waste deposition without irrigation, biogas production was 2.8-fold higher than in the case of totally flooded wastes.

Conclusions

The present study has shown that leachate recirculation is effective in enhancing the degradation rate of waste and gas production. Accessibility of water or landfill leachate stimulated biogas and methane production. A shortage or excess of water inhibited biochemical transformations in wastes.

Research reveales the impact of environmental conditions on biogas production. The lowest biogas production was observed when wastes were not irrigated by water or leachate (dry wastes) and in cases when wastes were totally flooded with water - (flooded wastes). In these cases biogas characterized the lowest methane content.

The highest effectiveness of biogas production and its best composition was achieved in wastes irrigated by leachate in the amount corresponding to double the amount of annual atmospheric precipitation.

The presented experiment shows that there is the possibility of biochemical processes controlling in waste heap for, e.g. energy piles, but in this case regulation of water conditions by means of water or leachate is important. However, there is then the necessity of optimization of the dosage and kind of recirculated medium.

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